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Saudi Arabian Solar Radiation Network and Data for Validating Satellite Remote-Sensing Systems

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ABSTRACT

The National Aeronautics and Space Administration (NASA) will be launching complex satellite remote-sensing platforms for monitoring the earth's radiation budget, land use, and atmospheric physics for periods exceeding 10 years. These Earth Observing Satellite (EOS) platforms will strive to detect man-made and natural variations in the Earth's climate. From 1993 to the present (1999), the National Renewable Energy Laboratory (NREL) and the King Abdulaziz City for Science and Technology (KACST) in Riyadh, Saudi Arabia, conducted a joint solar radiation resource assessment project to upgrade the solar resource assessment capability of the Kingdom of Saudi Arabia. KACST has deployed a high quality 12-station network in Saudi Arabia for monitoring solar total horizontal, direct beam, and diffuse radiation. One- and five-minute network data are collected and assessed for quality. 80% or more of the network data fall within quality limits of ±5% for correct partitioning between the three radiation components. This network will provide measured data for validating the NASA remote sensing systems. We describe the network, quality assessment procedures, and the results of estimating aerosol optical depth and precipitable water vapor. These are important for validating satellite estimates of radiation fluxes in and at the top of the Earth's atmosphere.

Keywords: Solar radiation, shortwave, longwave, network, instrumentation, validation, remote sensing, desert, Saudi Arabia, EOS

1. INTRODUCTION

The National Aeronautics and Space Administration (NASA) is deeply involved in an Earth Science Enterprise (ESE) program to monitor and develop an understanding of the total energy system of the earth and the effects of natural and human-induced changes on the global environment. NASA has established research themes in many disciplines, including climate variability and change. The Earth Observing Satellite (EOS) is the centerpiece of the ESE. It consists of a science component and a data system supporting a coordinated series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. One component of the EOS program, to be launched in July of 1999, is the Terra spacecraft platform, formerly called the EOS AM-1 spacecraft[1]. The platform will be put into a sun synchronous orbit with descending node at 10:30 AM local time. It will carry five instruments to monitor thermal radiation budget, atmospheric chemistry, the effect of clouds on the earth's energy budget, and land use. Figure 1 shows the platform during ground testing and instrument installation. Figure 2 is an artist's rendition of the platform on orbit. An important aspect of Terra and other EOS missions is validation of the various scientific data products generated by the sensors. Such products include estimates of the solar radiation fluxes in the atmosphere and on the ground that the sensors observe, and the atmospheric constituents that affect radiative transfer through the atmosphere, such as aerosols and water vapor.

Figure 1. TERRA satellite during ground installations and testing (NASA Photo)

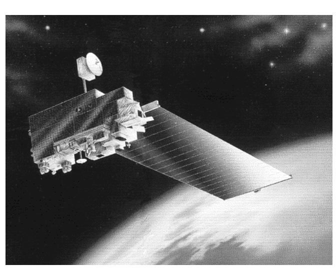


Figure 2. Artist's rendition of TERRA platform in orbit. (NASA)

From 1993 to the present (1999), the National Renewable Energy Laboratory's (NREL) Center for Renewable Energy Resources and the King Abdulaziz City for Science and Technology (KACST) in Riyadh, Saudi Arabia, conducted a joint solar radiation resource assessment project to upgrade the solar resource assessment capability of the Kingdom of Saudi Arabia[2]. The project is operated under Annex II, Solar Radiation Resource Assessment, to the Joint United States - Saudi Arabian Technical Agreement on Renewable Energy Research, and is called the New Energy Project. The goals of the project were to improve the monitoring of solar radiation resources for alternative energy within the Kingdom, train KACST scientists in the principles of solar radiation measurements, instrumentation, network operations, data quality assessment and management, solar radiation modeling, and to generate a solar radiation atlas for the Kingdom. The meeting of the goals of the New Energy Project has resulted in a solar radiation atlas for the kingdom, and deployment and operation of a high-quality 12-station network for monitoring solar total horizontal, direct beam, and diffuse radiation in the Kingdom.

NREL and KACST jointly proposed to the NASA EOS Validation Office that this recently established, high-quality solar radiation network data would be of great value for validation of EOS Terra data products. NASA agreed, and the NREL/KACST team is presently working to provide Instrument and Science Teams for the Terra platform instruments high quality Saudi Arabian surface solar radiation flux data. In addition, NREL has developed techniques for estimating the total column water vapor and aerosol optical depth from the measured meteorological and radiometric data.

2. SAUDI ARABIAN MONITORING NETWORK

Under the KACST New Energy Project, NREL undertook to assist KACST with the design of a solar radiation monitoring network, including selection of sensors, data loggers, instrument platform design, as well as data collection, quality assessment, and management. An Absolute Cavity Pyrheliometer[3] was obtained by KACST to serve as the calibration reference instrument, and a central calibration facility for solar radiometers was established at the KACST Solar Village site 40 Km northwest of Riyadh. KACST participated in the World Meteorological Organization (WMO) 1995 International Pyreheliometric Comparison (IPC)[4] in order to obtain traceability of their radiometer calibrations to the WMO World Radiometric Reference, or WRR.[5]

NREL and KACST evaluated METEOSAT satellite images of the Kingdom, and KACST personnel performed site visits to select sites representing the various climate, topographical, and albedo regimes in the Kingdom. Figure 3 is a map of the selected sites. Note that the sites represent a coarse 5° x 5° grid over the country. The Kingdom is approximately the size of Alaska and Texas combined, or roughly the eastern half of the United States. Riyadh is indicated on the map as the capital (see Figure 3), but is not one of the monitoring network sites. Figure 4 is a representation of the albedo features of the Arabian Peninsula as seen from space with exaggerated contrast.

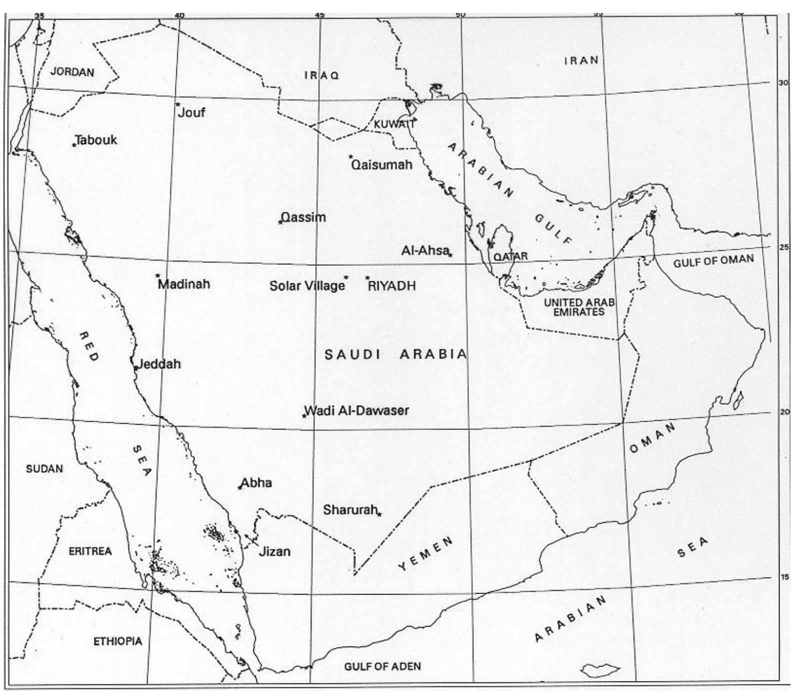


Figure 3. Saudi Arabian solar radiation monitoring network stations. Note Riyadh is the capital, and not a monitoring station. (NREL)

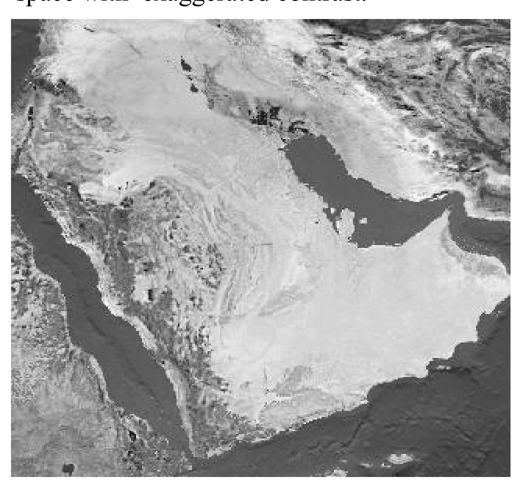


Figure 4. Enhanced representation of albedo features of the Arabian peninsula seen from space. (© The Living Earth, Inc.)

3. NETWORK INSTRUMENTATION

Instrumentation for the measurement of total solar radiation from the sky dome on a horizontal surface (global horizontal), direct beam radiation in a 5.7° field of view centered on the solar disk, and diffuse sky radiation on a horizontal surface as well as ambient temperature and relative humidity were selected as shown in Table 1.

TABLE 1. Instrumentation Common to All 12-Measurement Stations.

PARAMETER	UNIT	SENSOR	MANUF.	MODEL	UNCERTAINTY	COMMENTS
Ambient Temperature	°C	1000 Ω Plat. resistance thermometer	Vaisala	50 Y	+/- 0.5 °C	Combined temp. and RH sensor
Relative Humidity (RH)	% RH	Capacitive	Vaisala	50Y	+/- 2.5%	0%–100% range
Global Horizontal Solar Irradiance	W/m^2	Type -T thermopile pyranometer	Eppley Laboratory	PSP	+/- 3.0% @ 1 kW/m^2	Using single calibration factor
Direct Beam Solar Irradiance	W/m^2	Type -T thermopile pyrheliometer	Eppley Laboratory	NIP	+/- 2.0% @ 1 kW/m^2	5.7° field of view
Diffuse Horizontal Solar Irradiance	W/m^2	Type -T thermopile pyranometer	Eppley Laboratory	PSP	+/- 3.0% @ 1 kW/m^2	Under tracking shading disk subtending 5.7°
Solar Tracker: Direct Beam	n/a	Synchronous motor drive	Eppley Laboratory	ST-1	+/- 3.0° per day	Manual alignment daily
Solar Tracker: Shade Disk	n/a	Synchronous motor drive	Eppley Laboratory	RSD-2	+/- 3.0° per day	Manual alignment daily
Data Logger	V	Analog to digital sample and hold	Campbell Scientific, Inc.	CR-10	0.2% full-scale	Full-scale: 25 Mv Resolution 3.33 Mv Time +/- 4 ms noise < 0.8 µV RMS

All but Solar Village instrumentation is mounted 0.5 m above ground level on identical platforms. At sites with sandy soil , platforms are mounted on concrete pads. The Solar Village platform is located 4 m above ground on the building rooftop. The data sample period is 10 seconds (0.1 Hz), and 5-minute averages of the 10-second data are computed and archived. The clock accuracy for the data logger is +/- 2.0 sec/day. The clocks at all sites are set nightly with respect to national time standards. All network data are downloaded nightly to the Data Collection Center at the Solar Village site. Figure 5 is a photograph of the instrumentation platform designed by NREL for installation at all 12 stations.

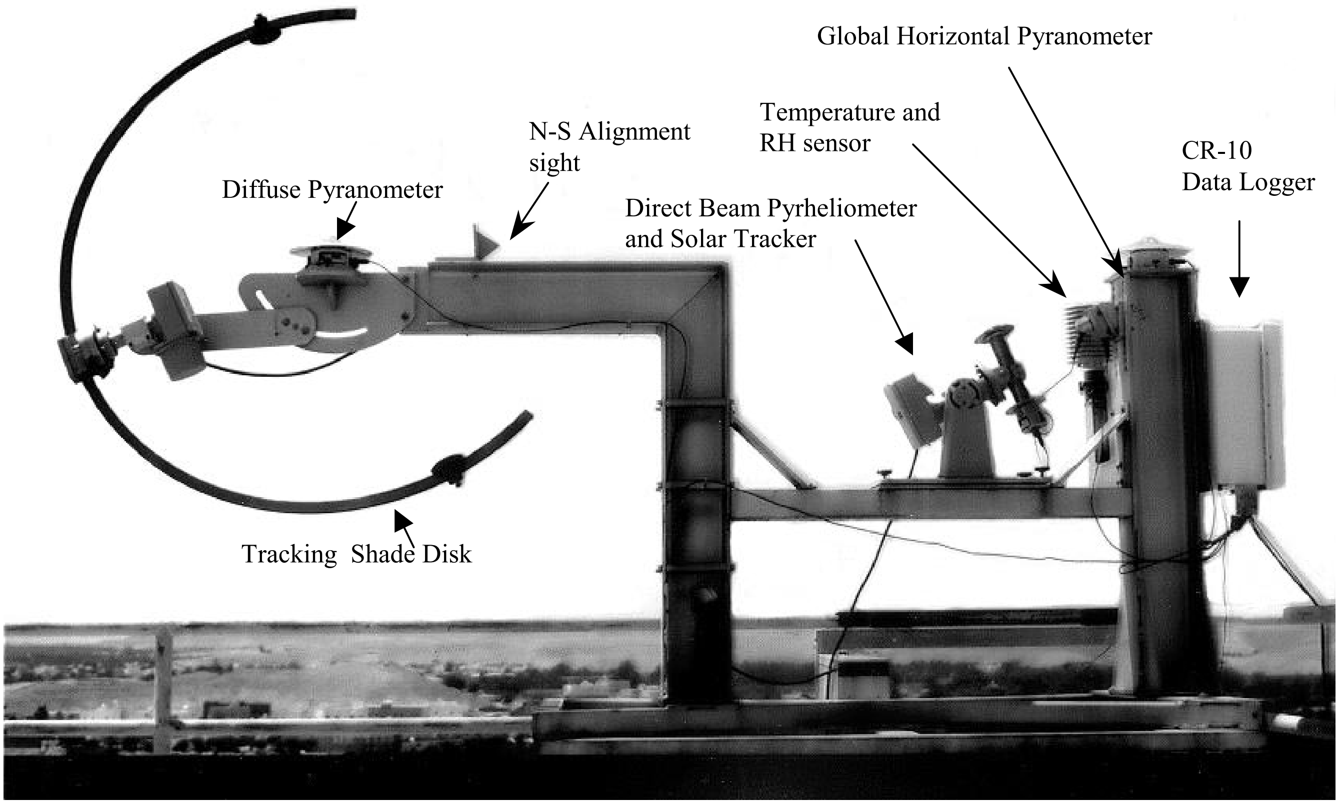


Figure 5. NREL-designed platform and instrumentation for monitoring total and diffuse global radiation on a horizontal surface, direct beam solar radiation, ambient temperature, and relative humidity. The platform is aligned along the meridian of longitude for the site, with the tracking shade disk mechanism to the south (NREL photo by Steve Wilcox).

4. CALIBRATIONS AND INSTRUMENT CHARACTERIZATION

The radiometers installed in the network are calibrated against the KACST reference absolute cavity pyrheliometer that participated in the 1995 WMO IPC at Davos, Switzerland. Thus, all calibrations are traceable to the WMO WRR. NREL developed Radiometer Calibration and Characterization (RCC) software to automatically collect calibration data, generate calibration reports, and archive calibration results. The calibrations are derived from the measurement of the direct beam radiation by the absolute cavity radiometer, measurement of the diffuse sky radiation by a pyranometer under a tracking shading disk, and computation of the reference (global horizontal) irradiance using: $I_{ref} = I_{dn} * \cos(z) + I_{diff}$, where I_{dn} is the direct beam, I_{diff} is the sky diffuse radiation, and z is the zenith angle (complement of the solar elevation angle), which, for horizontal surfaces represents the incidence angle for the solar direct beam.

Calibrations are accomplished with the radiometers mounted specially designed platforms on a roof at the Solar Village site. Data are taken from sunrise to sunset on several clear days. Silicon diode radiometers monitor atmospheric stability during the calibrations. Any variation in direct or global irradiance of more than 0.5% between 30-second readings results in their being excluded from the analysis. The software generates a report of each individual instrument's departure from true lambertian (cosine) response in 10°-wide bins of zenith angle from 0° to 90°. Figure 6 shows the graph of the responsivity of an individual instrument as it is generated in the calibration report. Table 2 is a report of the zenith angle dependence of the responsivity generated by the RCC report generator.

The uncertainty in the responsivity is computed from the range of the calibration data in each zenith angle bin, root sum squared with a base level of uncertainty of 1.3%. The base uncertainty level was determined through a detailed uncertainty analysis of the transfer of the WRR scale to the cavity pyrheliometer, time-keeping and location data, and specifications and testing of the data logger used.

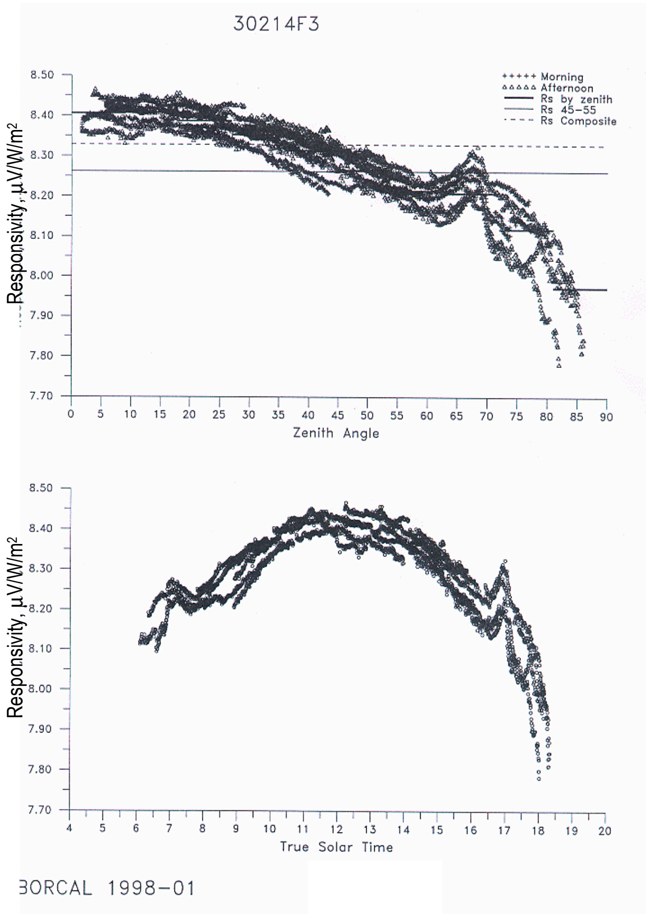


Figure 6. RCC Graphical report of pyranometer responsivity (µV/W/m²) -vertical axis- as a function of zenith angle (top) and true solar time (bottom) for a Saudi-network pyranometer.

Table 2. RCC Responsivity Report Format

Instrument			**30214F3**
N/StdDev			**7248/0.035**
Bin	**Rs**	**Uncert**	**Pct**
45-55	8.262	0.18	2.2
Composite	8.328	0.45	5.4
Zen 00–09	8.406	0.18	2.1
Zen 09–18	8.408	0.17	2.0
Zen 18–27	8.387	0.18	2.1
Zen 27–36	8.353	0.19	2.2
Zen 36–45	8.314	0.20	2.4
Zen 45–54	8.265	0.18	2.2
Zen 54–63	8.214	0.18	2.2
Zen 63–72	8.208	0.25	3.0
Zen 72–81	8.118	0.28	3.4
Zen 81–90	7.972	0.27	3.3

Key to table entries:

N/StdDev: N = sample size entire data set; StdDev is standard deviation in µV/W/m²
Rs: Responsivity (µV/W/m²) in zenith angle bin
Uncert: uncertainty in mean for bin (± µV/W/m²)
Pct: uncertainty in mean for bin as ± percent of Rs
45–55: Responsivity in 45–55 zenith angle bin (µV/W/m²)
Composite: Mean responsivity computed from all cosine (bin center) weighted responsivities.
Zen nn–nn: Zenith angle bin boundaries

The instrumentation for performing the calibrations consists of an Eppley laboratories Automatic Hickey-Frieden (AHF) absolute cavity pyrheliomter, two shaded pyranometers that are averaged to produce the diffuse sky irradiance, and silicon cell pyranometers and pyrheliometers to measure the sky stability. Data are recorded on a John Fluke Model 2287A Helios data logger with 100 µV resolution, less than 50 nV of noise, and 0.05% of full-scale accuracy. The full-scale used is 25 mV.

All calibration data and results are archived into a calibration history database that is an integral part of the RCC software. Given the calibration and deployment history of a particular radiometer we are able to correct data collected using a single calibration factor (usually the 45–55 result) to account for individual radiometer cosine responses. These corrections reduce the uncertainties in radiometric data at high zenith angles by at least a factor of two.

5. NETWORK OPERATIONS

5.1 Station Locations

Table 3 shows station name and location information for the entire 12-station network. See Figure 3 above for a map of station locations. All of these stations are configured with instrumentation as described in Section 3 above, and shown in Figure 5.

TABLE 3: Saudi Arabian Solar Monitoring Network Stations

Station	Latitude (°N)	Longitude (°E)	Elevation (m)
Abha	18.23	42.66	2039
Al-Ahsa	25.30	49.48	158
Gizan	16.90	42.58	7
Qassim	26.31	43.77	647
Jeddah	21.68	39.15	4
Madinah	24.55	39.70	66
Qaisumah	28.32	46.13	358
Sharurah	17.47	47.11	735
Jouf	29.79	40.10	669
Solar Village(*)	24.91	46.41	650
Tabouk	28.38	36.61	768
Wadi Al-Dawaser	20.44	44.68	701

*Northwest of Riyadh

5.2 Baseline Surface Radiation Network Station Upgrade for the Solar Village Site

In addition to the regular network installation described in Section 3 and shown in Figure 5, KACST took the initiative to obtain improved instrumentation to upgrade the Solar Village network station to stringent WMO Global Climate Change Research Program Baseline Surface Radiation Network (BSRN)[6,7] standards. This included the addition of an all weather absolute cavity radiometer for direct beam radiation monitoring, upwelling and downwelling infrared (pyrgeometer) sensors, upwelling shortwave radiation sensor, and a more accurate tracking system for direct beam and shading mechanisms. The upwelling shortwave and longwave sensors are mounted on a tower 33 m above ground. Figure 7 is a 360° panorama around the base of the 33-meter tower, where the upwelling longwave and shortwave instrumentation are located. The rest of the BSRN instrumentation is located 1 km to the southwest, on the roof of the calibration as seen in Figure 5. The Solar Village BSRN data are collected and archived as 1-minute averages of 2-second samples.

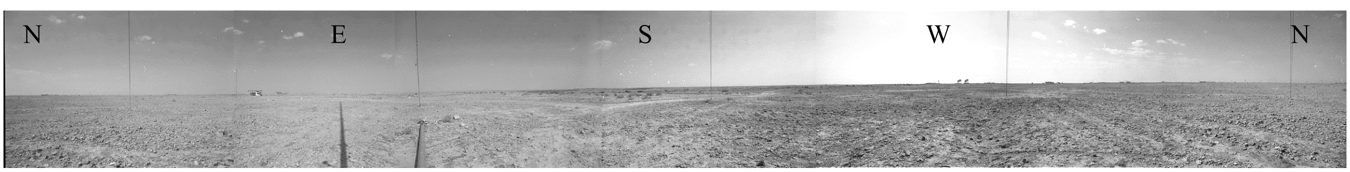


Figure 7. 360° panorama around base of 33-m tower in September of 1998. Upwelling shortwave and longwave radiation is measured with downward looking pyrgeometer and pyranometer at this site (NREL photo by Steve Wilcox).

5.3 Data Collection and Quality Assessment

The 12-station Saudi Arabian Solar Monitoring Network 5-minute surface flux, temperature, and relative humidity data are collected nightly. Data are downloaded via modem lines from data logger memory to the central Solar Village calibration and data-processing facility. Data collection is unaffected and uninterrupted by this data transfer.

The previous day's data are examined by the network manager find obvious measurement problems, such as failed trackers or sensors. Then, the data are processed through a Data Quality Management System (DQMS) that performs checks on the relative partitioning of the radiometric data and whether the data exceeds physical limits. Since the total global solar radiation, $I_{GH,}$ is made up of a combination of the direct beam and diffuse sky radiation, namely : $I_{GH} = I_{DN} *\cos(z) + I_{DF}$, where I_{DN} is the direct beam, I_{DF} is the sky diffuse radiation, and z is the zenith angle (incidence angle for direct beam on a horizontal surface), the measured data are inserted into this equation, and the quality of the balance between components is used to check the data quality.

Quality assessment flags are assigned based on the magnitude and direction of deviations from the balance in the radiation component equation. For convenience, the evaluation is performed after normalization with respect to the extraterrestrial

Figure 8. Visual display of quality assessment (QA) flags and normalized radiation values of one month of 5-minute solar data. The dark rectangle of larger QA flags (large errors) on Wednesday, 22 July, from 6:30 AM to 10:00 AM corresponds to a failed diffuse-shade tracker, indicated by the high (white) diffuse value in Kd.

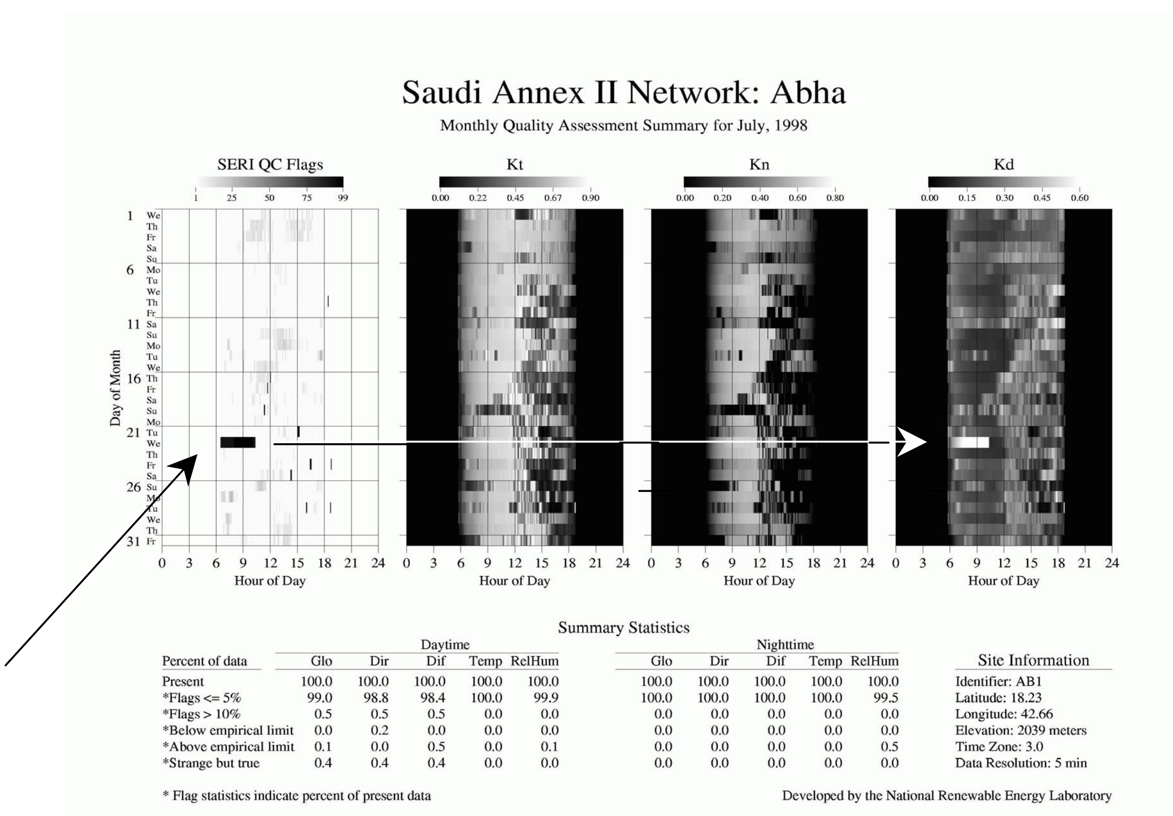
(ETR) solar radiation for the appropriate radiation component. The normalized variables are called "clearness" or "cloudiness" indices[8], and we refer to them as "K-space" parameters. These K-space parameters are defined as

- Kt = Irradiance from 2-pi steradian (sr) on horizontal surface / [ETR direct beam * cos (z)]
- Kn = Direct beam irradiance in 5.7° field of view / ETR direct beam
- Kd = Diffuse (non-direct beam) Irradiance from 2-pi sr on horizontal surface / [ETR direct beam * cos (z)].

ETR direct beam is computed from the "nominal" solar constant of 1367 W/m^2 +/- 7 W/m^2 modified by the inverse square law applied to the daily variation in the earth-sun radius vector caused by the eccentricity of the Earth's solar orbit.

In K-space, the component balance equation reduces to Kt = Kn + Kd. K-space parameters generally are in the range from 0 to 0.8. Data quality assessment flags in the range from 00 to 99 are assigned that describe both the magnitude and possible source of imbalance in the component equation. Flags in the range from 00 to 09 indicate various low-level failures identified by visual inspection. Flags from 10 to 93 indicate failures in one of four ways. The manner of failure (high or low) is indicated by the remainder of the calculation (flag + 2)/4. The magnitude of the test failure (distance in K-units) is determined from: d = (INT (flag +2)/4)/100. Flags from 94 to 97 indicate that data fall into a physically impossible region where Kn > Kt. Flag 98 is not used, and Flag 99 indicates missing data.

A visual interpretation tool developed in conjunction with the DQMS processing allows one to examine the 5-minute data and the magnitude of flags associated with the data in K-space, as shown in Figure 8. In the SERI QC Flags section of the Figure 8, the darker the shading, the "worse" the flags. In the Kt, Kn, and Kd sections, the lighter the shades—the higher the irradiance, and the darker the shades—the lower the irradiance.



In Figure 8, there is a diurnal pattern for this month of sunny mornings and partly cloudy afternoons. Up until the 22nd of the month, the flags are light (small errors), but there are several hours on the 22nd when the flags are large (dark rectangle from 7 to 9:30 AM). On the same row for the Kt, Kn, and Kd plots, the bright rectangle in the Kd segment on the 22nd indicates the tracking shading disk for the diffuse was not shading the pyranometer (high Kd). Thus, the component balance equation was not true, and the software flagged the data. By 10:30 AM, the station operators corrected the problem. The monthly summary shows that better than 98% of the data were flagged as having errors of less than 5% in the component balance equation, and 0.5% of the data had errors greater than 10%. Both KASCT and NREL process all data for the entire network with this product as part of a monthly network performance report.

6. DATA ISSUES AND AVAILABILITY

As the need for more accurate (lower uncertainty) solar radiometric data has grown in the climate change, global circulation model, and remote sensing arenas, more attention has been devoted to identifying the sources of discrepancies between measured and computed solar fluxes in the atmosphere. A more detailed examination of the characteristics of radiation sensors, such as geometrical and thermal responses, is required to reduce the instrument contributions to uncertainty. Therefore, we need to apply cosine response corrections and thermal (zero offset) corrections to measured shortwave radiation[9].

Figures 9a and 9b illustrate how pyranometer data for global horizontal solar radiation deviates from that derived from the diffuse and direct beam data as a function of season. The irradiance data for direct, global, and diffuse is shown in thin, dark lines, and relates to the left-hand scale. The computed-measured irradiance difference is shown in the light, thick line, corresponding to the right-hand scale. In the summer (top panel of Figure 9), the pyranometer apparently measures low versus the computed irradiance at midday and high in the mornings and afternoons. In the winter (bottom panel of Figure 9) the pyranometer consistently reads low all day long. This is consistent with the changing solar geometry throughout the seasons as it relates to the geometrical response of the pyranometers reported by our RCC software. Applying zenith angle dependant responsivities to the measured data should reduce these discrepancies.

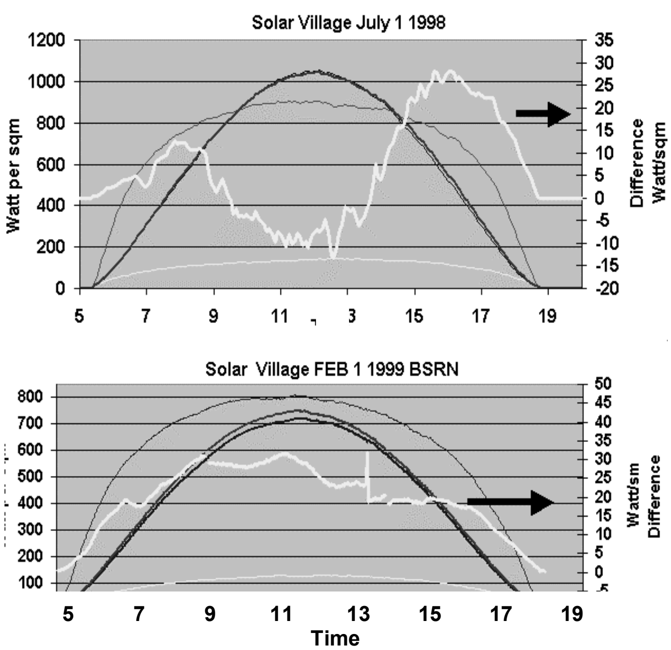


Figure 9 (Top panel). Deviation (thick light line, right scale) of measured total solar radiation from that computed from direct and diffuse radiation is shown for July 1 1998 at the Solar Village.
Figure 9 (bottom panel). Same for February 1, 1999, showing changes in pyranometer responsivity through seasons caused by changing solar geometry (zenith angle conditions throughout a day).

Because each measurement station incorporates both direct normal and diffuse sky measurements, the total global horizontal irradiance is most accurately represented by computing it from the direct and diffuse. The only sources of error in this calculation are the random and bias errors in the direct normal measurement and any thermal offsets or errors in the calibration factor of the diffuse measuring pyranometer.

Figure 10 plots the night-time thermal offset in an Eppley Pyranometer as a function of the net longwave radiation. Corrections to pyranometer measurements of global and diffuse during the daytime, with longwave flux of about 100 W/m² result in corrections of 4 W/m² for this radiometer.

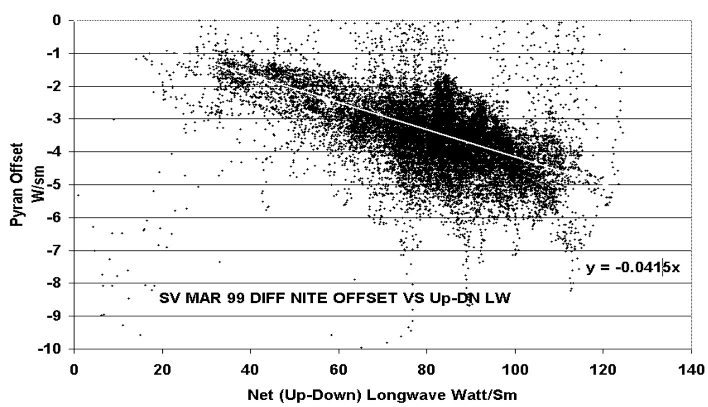


Figure 10. Night-time thermal offset in a pyranometer as a function of net (Upward - Downward) infrared radiation balance (Solar Village).

Monthly quality assessed data files, for all 12 stations and the BSRN station at the Solar Village, are forwarded to NREL. NREL post processes the global solar radiation data to correct for zenith angle variations in the responsivity of the pyranometer measuring the total sky radiation. All data then is posted on the NREL supported Web site at **http://rredc.nrel.gov/solar/new_data/Saudi_Arabia/.** From this site, NASA Terra instrument teams have access to all 5-minute network station data from January 1998 to the present. The Solar Village 1-minute resolution BSRN data are formatted and posted on the above site, and is also reformatted and submitted to the BSRN Archive in Zurich, Switzerland, (at **http://bsrn.ethz.ch/**)in the BSRN Archive format

7. ESTIMATING ATMOSPHERIC PARAMETERS

While developing a 30-year hourly National Solar Radiation Database for the United States[10], NREL developed methods of estimating total column water vapor[11] and aerosol optical depth[12] (AOD) from relative humidity and direct normal solar radiation observations. Recent work by Molineaux et al.[13] have shown that AOD derived from broad-band direct normal radiation is equivalent to monochromatic AOD at a specific wavelength. NREL is independently applying our techniques in conjunction with the Saudi Arabian network data collection. At the Solar Village BSRN station, we also have the benefit of a CIMEL™ Electronique Model CE318 sunphotometer, on loan from the NASA Aerosol Robotic Network (AERONET)[14]. This photometer provides aerosol optical depth at 7 wavelengths and total column water vapor on a near real time basis. The AERONET sunphotometer data are available from Goddard Space Flight Center on the Internet at the following URL: **http://aeronet.gsfc.nasa.gov:8080/.**

In Figure 11, the total column water vapor at the Solar Village station for March of 1999 was estimated using the NREL algorithms and is compared to total column water vapor derived from the NASA CIMEL sunphotometer data.

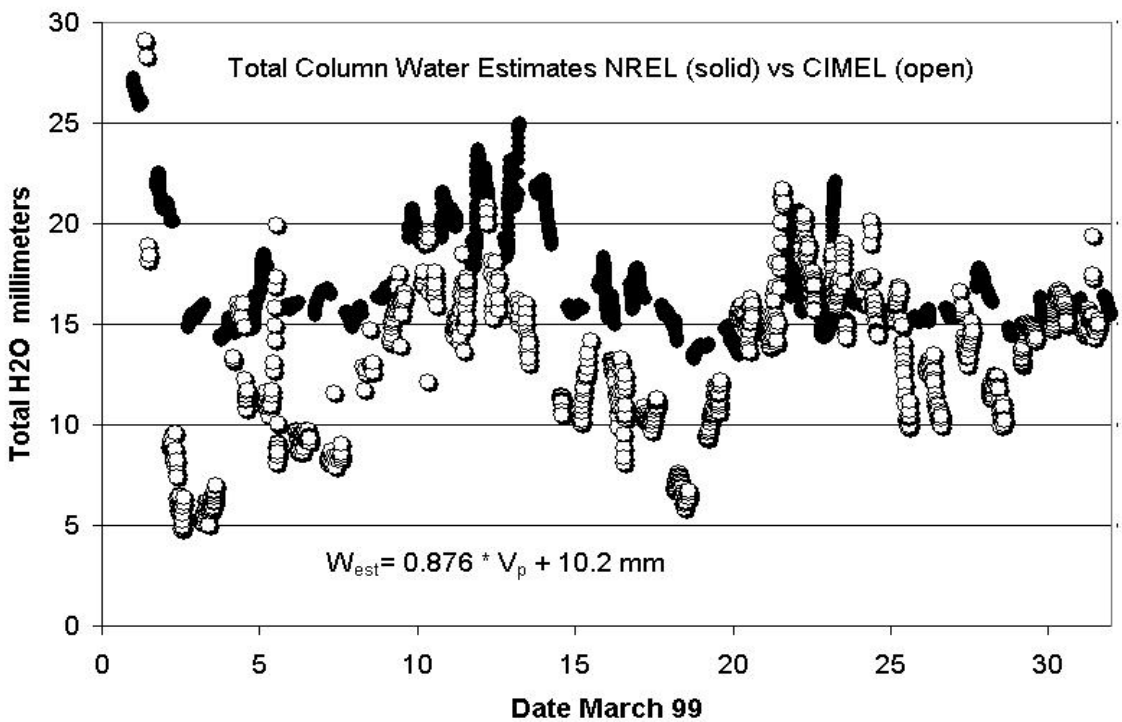


Figure 11. Comparison of NASA CIMEL-derived total column water (open circles) and NREL estimates from saturation vapor pressure derived from relative humidity data (filled circles) for March of 1999 at the Solar Village Station.

Figure 12 is a comparison of NREL-derived estimates of aerosol optical depth for the Solar Village Station compared with the AOD at 500 nm derived from the CIMEL sunphotometer installed at the site in February of 1999. NREL will apply these algorithms using the Saudi Arabian network radiation and meteorological data to estimate these parameters for each of the network stations.

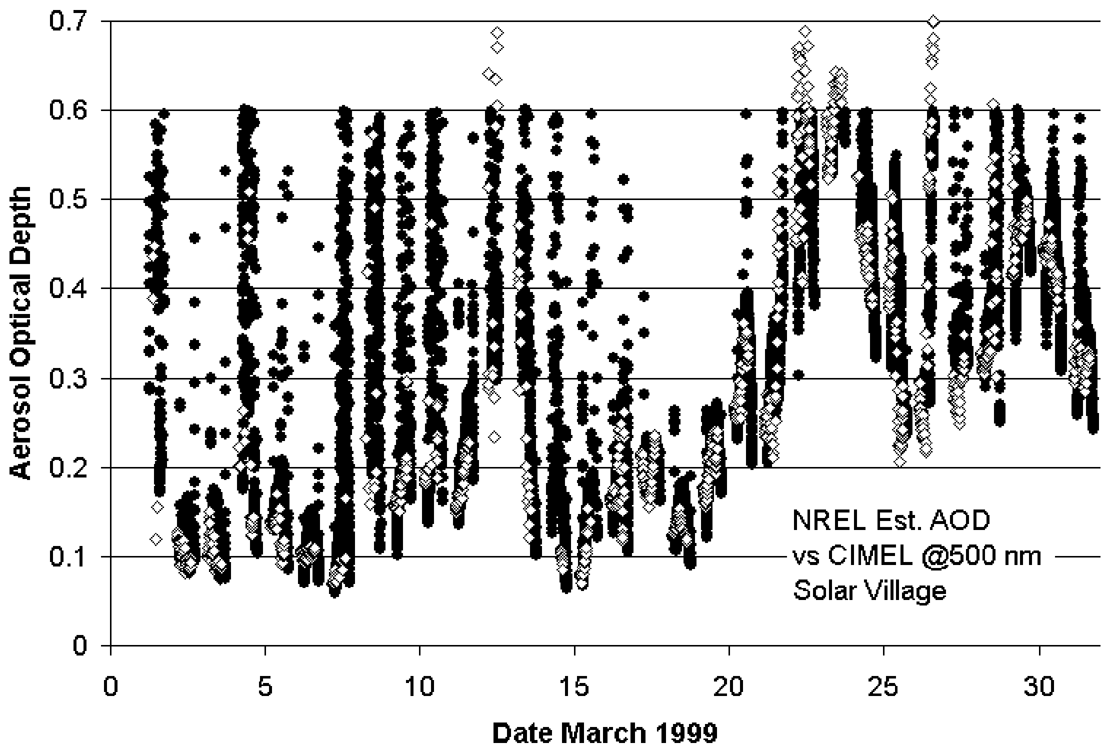


Figure 12. Black points are estimated aerosol optical depth for March of, 1999, from Solar Village BSRN data. Open diamonds are CIMEL sunphotometer AOD at 500 nm.

The daily profiles of water vapor in Figure 11 match rather well, but there are occasional biases between the two estimates of about 5 mm. The two monthly means for total water vapor for March 1999 differ by 0.31 cm (NREL mean =1.68 cm, CIMEL mean = 1.37 cm). Standard deviation of the monthly mean total column water was 2.46 cm for the NREL estimates, and 3.59 cm for the CIMEL estimates. The agreement of daily profiles of aerosol optical depth in Figure 12 are also good, especially in low-air mass situations near the middle of the day. For 866 occurrences of concurrent AOD estimates in March, 1999, the monthly average AOD from both sources only differ by 0.01 in optical depth (NREL = 0.29 vs CIMEL = 0.30), but the standard deviation of the NREL estimates of monthly mean AOD for March, 1999 (0.28) is twice that of the CIMEL standard deviation (0.14). With continued comparison and correlation of the data from the NREL estimates and the CIMEL photometer, we hope that refined algorithms for estimating both aerosol optical depth and water vapor from surface broad-band radiation flux can be generated.

8. SUMMARY

In the Kingdom of Saudi Arabia, NREL and the Energy Research Institute of KACST conduct a joint solar radiation resource assessment project to upgrade the solar resource assessment capability of the kingdom. KACST has deployed a high quality 12-station network in Saudi Arabia for monitoring solar total horizontal, direct beam, and diffuse radiation. One-and five-minute network data are collected and assessed for quality. 80% or more of the network data fall within quality limits of ±5% for correct partitioning between the three radiation components. NREL post processes this data to correct for known zenith angle dependence of the calibration factors used to produce the total radiation flux at the ground. The quality assessed and corrected network data are available to the TERRA instrument teams through an NREL Internet site. One-minute resolution BSRN quality data from the Solar Village site, 40 km northwest of Riyadh, is posted on the same NREL internet site, and reformatted and submitted to the BSRN Archive in Zurich Switzerland. The measured data supports validation of the NASA remote-sensing systems deployed on the TERRA EOS. NREL estimates of AOD and precipitable water vapor, important for validating satellite estimates of radiation fluxes, can be derived from the radiometric and meteorological data for comparison with in-situ sunphotometer estimates and derived satellite estimates of these atmospheric parameters.

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